

AU colloquium 08/27/10

Title: Solar Sailing is not Science Fiction Anymore

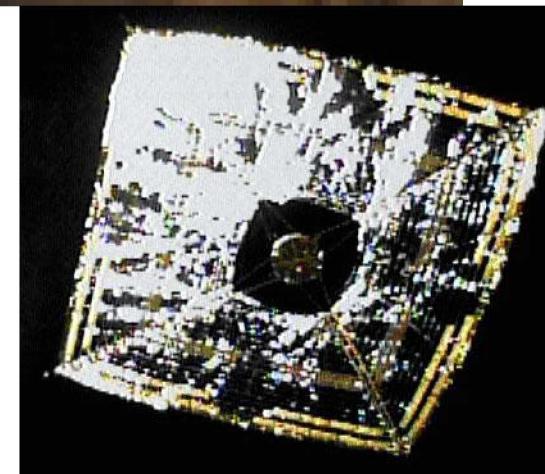
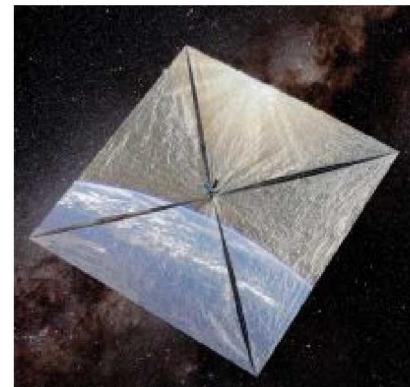
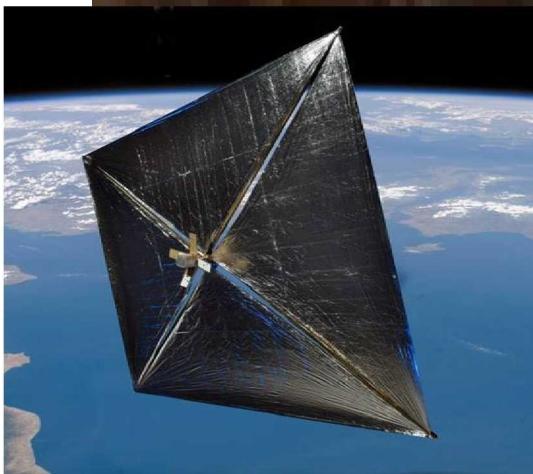
Abstract:

Over 400 years ago Johannes Kepler envisioned the use of sunlight to propel a spacecraft. Just this year, a solar sail was deployed in orbit for the first time and proved that a spacecraft could effectively use a solar sail for propulsion. NASA's first nano-class solar sail satellite, NanoSail-D was designed and developed in only four months. Although the first unit was lost during the Falcon 1 rocket failure in 2008, the second flight unit has been refurbished and is waiting to be launched later this year. NanoSail-D will further the research into solar sail enabled spacecraft. It will be the first of several more sail enabled spacecraft to be launched in the next few years. FeatherSail is the next generation nano-class sail spacecraft being designed with the goal to prove low earth orbit operational capabilities. Future solar sail spacecraft will require novel ideas and innovative research for the continued development of space systems. One such pioneering idea is the Small Multipurpose Advanced Reconfigurable Technology (SMART) project. The SMART technology has the potential to revolutionize spacecraft avionics. Even though solar sailing is currently in its infancy, the next decade will provide great opportunities for research into sailing in outer space.



Solar Sailing is Not Science Fiction Anymore and other musings by

Dean Alhorn



“Twenty years from now you will be more disappointed by the things you didn't do than by the ones you did do. So throw off the bowlines. Sail away from the safe harbour. Catch the trade winds in sails. Explore. Dream. Discover.”

-Mark Twain

Acronyms, Acronyms, Acronyms

- AU – Auburn University
- UA – University of Alabama
- UNM – University of New Mexico (Go Lobos!)
- MIT – Massachusetts Institute of Technology
- NASA – National Aeronautics and Space Administration
- RUM – Rotating Unbalanced Mass
- AAMSS – Autonomous Assembly of Modular Structures in Space
- STABLE – Suppression of Transient Accelerations By Levitation Evaluation
– **Sanders and Tolley Attempt Blind Leap at Engineering**
- AXAF – Advanced X-ray Astrophysics Facility (Chandra)
- g-LIMIT – GLovebox Integrated Microgravity Isolation Technology
- FASTSAT – Fast Affordable Science and Technology SATellite
- NSD – NanoSail-D
- IKAROS – Interplanetary Kite-craft Accelerated by Radiation Of the Sun
- SMART – Small Multi-purpose Advanced Reconfigurable Technology
- PUMCODOXPURSACOMLOPOLAR
 - Pulse Modulated Coherent Doppler-Effect X-Band Pulse-Repetition
 - Synthetic-Array Pulse Compression Side Lobe Planar Array

How to make a good acronym in two steps

ACRONYM –Abbreviated Code Rarely Or Never Yielding Meaning

Step 1 – Use active verb that describes the basic function.
(i.e. STABLE)

Step 2 – Fit meaningful words into the letters or combination of letters that describe the concept.
If suitable word cannot be found, use a mythical or a noun that describes the concept.

(i.e. Project relates to heat – use FIRE, or BLAZE)

A good acronym that describes the project will sell the idea.

Who am I and why am I here?

- Dean Alhorn
 - BSME from UNM
 - SM from MIT
 - 19 years @ NASA in Control and Signal Conditioning Electronics Group
 - 12+ Patents
 - Numerous Publications
 - MSFC Inventor of the Year-1995
 - Space Flight Awareness Award
 - NanoSail-D Principal Investigator
 - SMART Principal Investigator
 - Homeschool our 4 sons
 - Ages 13, 9, 7, 4

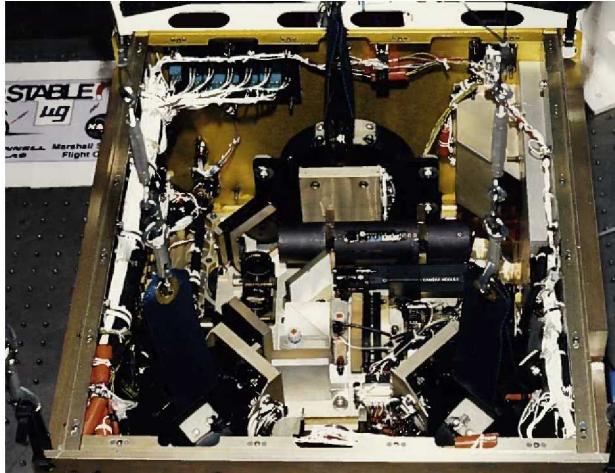


So what have I done in the past 19 years?

RUM



STABLE



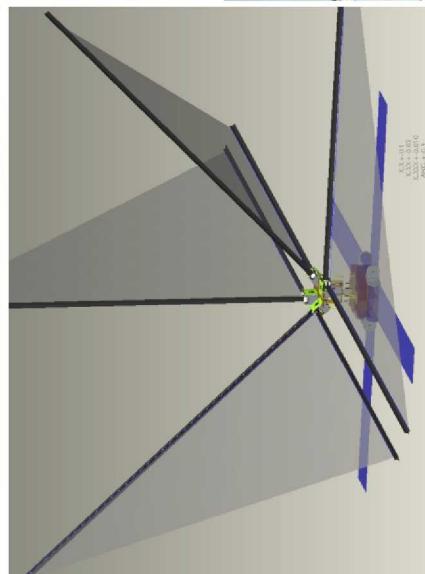
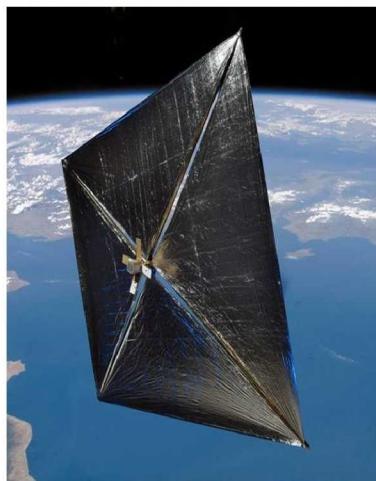
g-LIMIT



FASTSAT

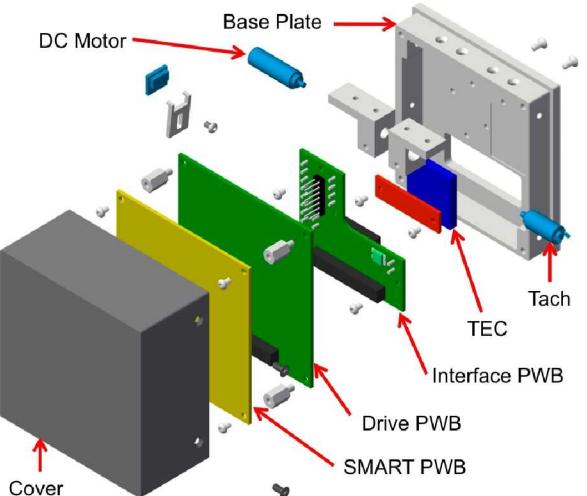


NanoSail-D



Chandra

SMART Demonstration Unit for MisST Flight
82.5mm x 82.5mm x 44.5mm ~ 300gms



SMART

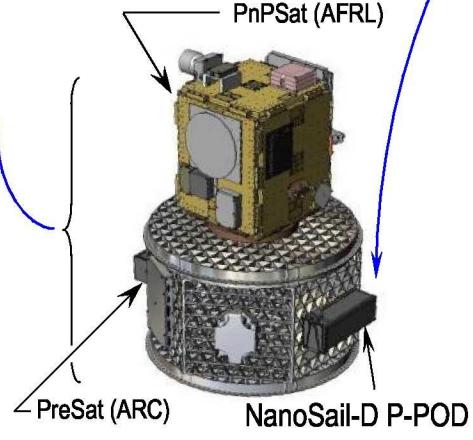
NanoSail-D History

1. CubeSail effort 05/07 – 12/07
2. NanoSail-D ATP 01/08 for delivery late April 2008. (4 months!)
3. Design and manufactured two flight units, SN001 and SN002
4. Delivered SN001 and SN002 to ARC for final integration April 21st, 2008
5. Performed final integration with ARC bus, completed 05/05/08
 1. Performed post integration vibration and shock testing
 2. Performed ground station checkout verification
6. Flight units delivered to Kwajalein, 06/08
7. SN001 integrated into P-POD on launch vehicle June 9th, 2008
8. Falcon 1 third launch, August 3rd, 2008
 1. Falcon 1 vehicle failed to achieve orbit, total loss of NanoSail-D SN001
9. NanoSail-D SN002 returned to ARC and placed in controlled storage

NanoSail-D SN001 History

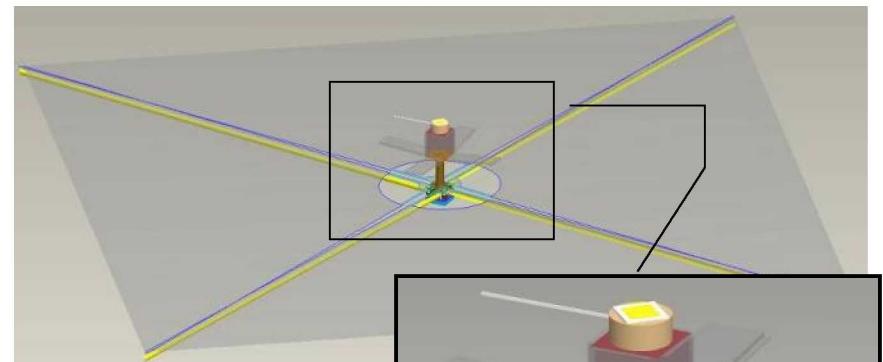
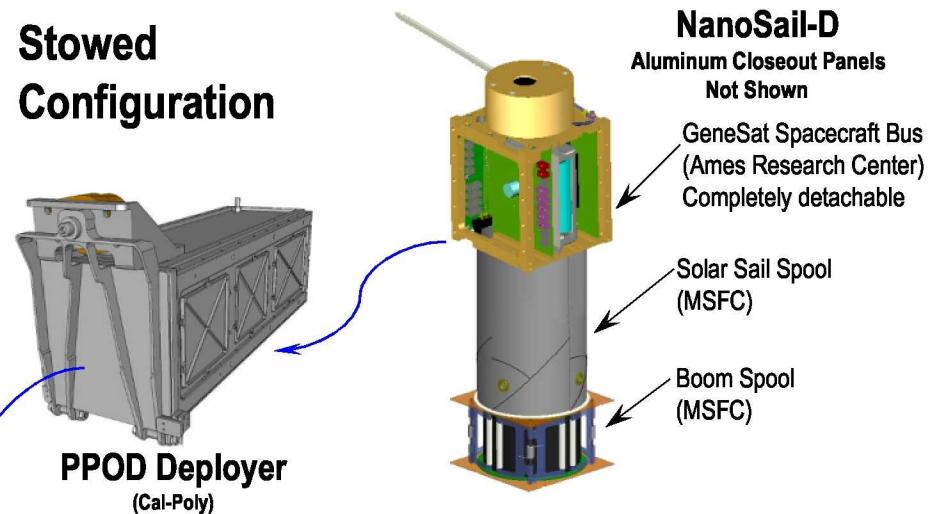
NanoSail-D SN001 Mission 01/08 – 08/08

- Objectives
 - Primary
 - Sail Stow & Deploy
 - Secondary/Opportunity
 - Ground Imaging
 - De-orbit Maneuver
- Relevance: Future low cost, nanosat science & technology missions will be more capable with the addition of flight proven technologies in:
 - Gossamer deployable structures
 - De-orbit systems



Launch Date: 3 August 2008
Launch Vehicle Failed to reach orbit.
Loss of NanoSail-D SN001

Stowed Configuration

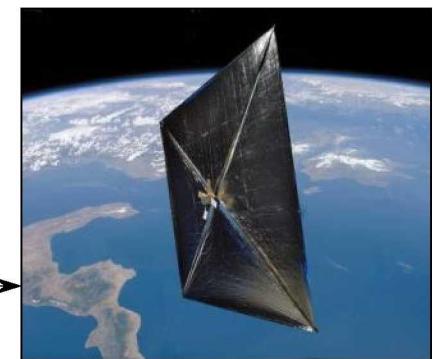
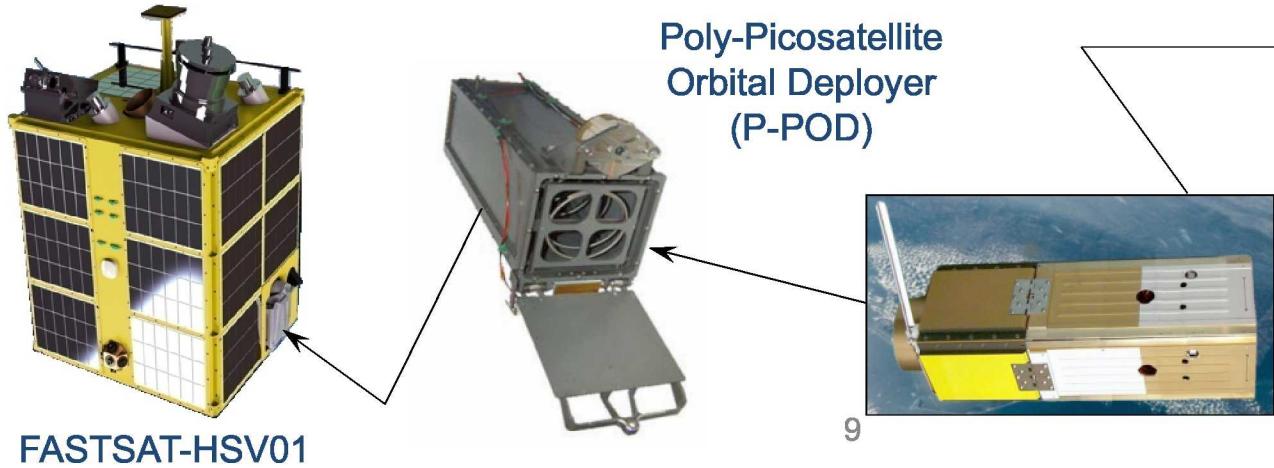


- ~10 m² Sail Area
- 2.2 m TRAC Booms
- Single Sail Spool
- Single Boom Spool
- Permanent Magnet Passive Stabilization

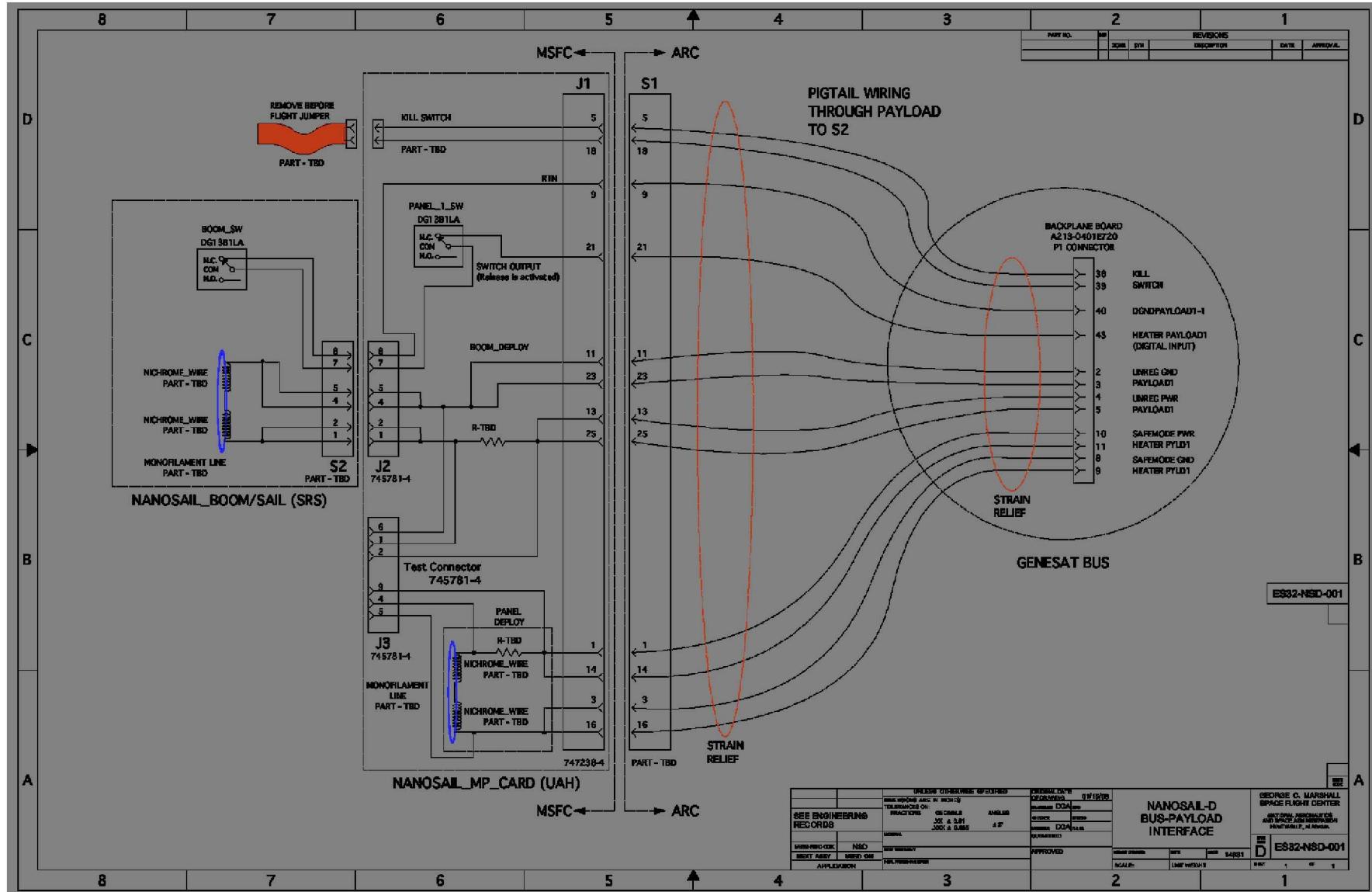
Deployed Configuration

NanoSail-D2 — 2009

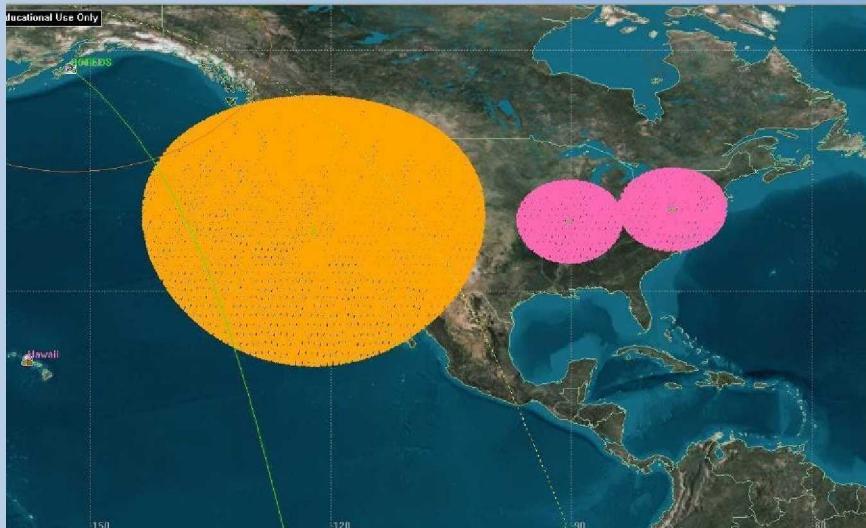
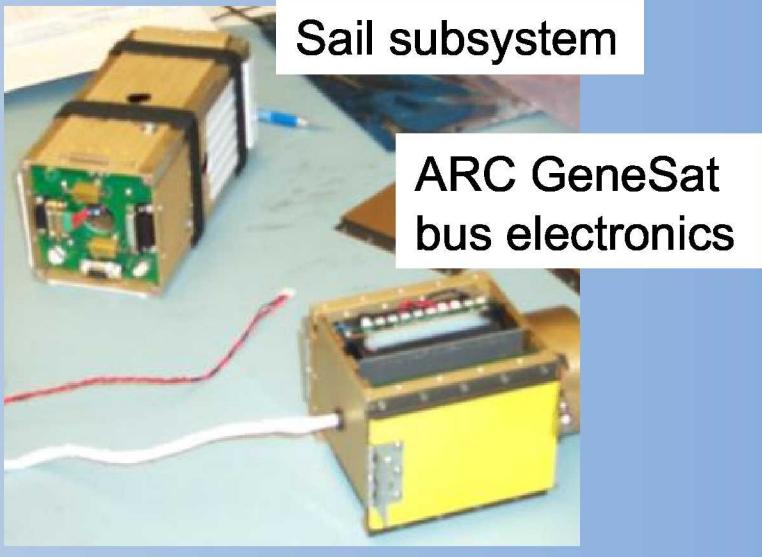
- **NanoSail-D was identified as payload candidate for flight on FASTSAT-HSV01 mission**
 - **NanoSail-D presented to the mid-SERB panel in April 2009**
 - Objective 1: Demonstrate the capability of the FASTSAT-HSV spacecraft to launch a nanosatellite while minimizing recontact.
 - Objective 2: Demonstrate the capability of the NanoSail-D nanosatellite to deploy a highly compacted solar sail/boom system and to validate de-orbit functionality.
 - **Developed Experiment Requirements Document (ERD) and O&IA for STP-26 launch.**
 - **Received ATP to refurbish SN002 unit for STP-26 mission.**



Keep it simple!



Utilize the experience and capabilities of others!



Make sure you can get the data you need!

Data is only as good as you can interpret it.

NanoSail-D Summary Sheet

Beacon Format (Transmitted every 10 seconds continuously)
 Flight 1: 437.269MHz, Network Addr: 6000, Encrypt Key: 6000, Unit Addr: 600, PW: 0x6666
 Flight 2: 437.270MHz, Network Addr: 7000, Encrypt Key: 7000, Unit Addr: 700, PW: 0x7777

Size (bytes)	Field	Details
1	Software Version Number	Set to 120 for flight
1	Burn Time	Set to 15 for flight
2	Start Phase	Set to 0 for flight
2	Current Phase	30 second increments
1	Switch State	Real-time value of switch
1	Panel Deploy Status	Indicates panel deployed
1	Sail Deploy Status	Indicates sail deployed
2	Startup Counter	Number of satellite resets
1	Power Port	Subsystem power indicators. 138: Beacon ON, S-Band OFF 139: Beacon ON, S-Band ON
2	Battery Voltage	Volts= 0.0179*Counts - 3.9930
2	Temperature	Satellite bus temperature
3	Satellite Timestamp	Current satellite time (seconds)
3	Satellite Ejection Time	Time at last power up (seconds)
3	Sail Deployment Time	Time of start of burn sequence (seconds)

Mission Timeline (T=Elapsed Time, P=Current Phase)

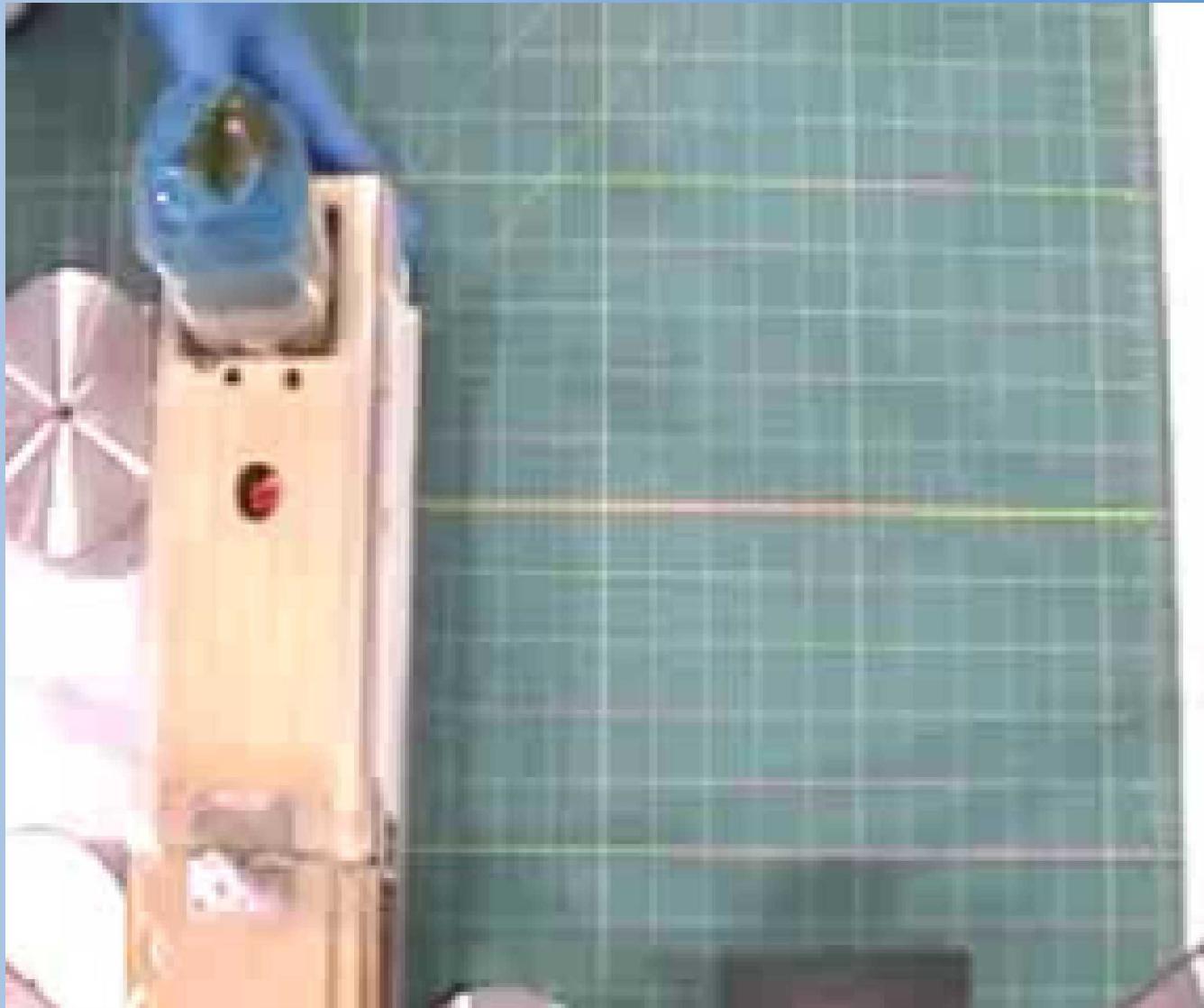
T=00:05:00 (P=0010)	: Deployment (Satellite ON, Beacon ON, S-Band OFF)
T=72:05:00 (P=8650)	: Start of Burn Sequence
T=72:06:00 (P=8652)	: Burn Panel Wire (1st attempt)
T=72:06:30 (P=8653)	: Burn Panel Wire (2nd attempt conditional)
T=72:07:00 (P=8654)	: Burn Panel Wire (3rd attempt conditional)
T=72:07:30 (P=8655)	: Burn Sail Wire (1st attempt)
T=72:08:00 (P=8656)	: Burn Sail Wire (2nd attempt conditional)
T=72:08:30 (P=8657)	: Burn Sail Wire (3rd attempt conditional)
T=72:09:00 (P=8658)	: S-Band ON
T=84:09:00 (P=8659)	: Satellite OFF

Contingency
 IF (Panels or Sail did not deploy) AND (Startup Counter = 60) THEN Goto P=8650
 IF (Panels or Sail did not deploy) AND (Battery Voltage < 6.7V for 30 minutes) THEN Goto P=8650

Ground Station Commands

Enable (BUS, 0x04)	: Burn Panel Wire
Enable (BUS, 0x02)	: Burn Sail Wire
GetPage(BUS, 0x1018)	: Get Log File

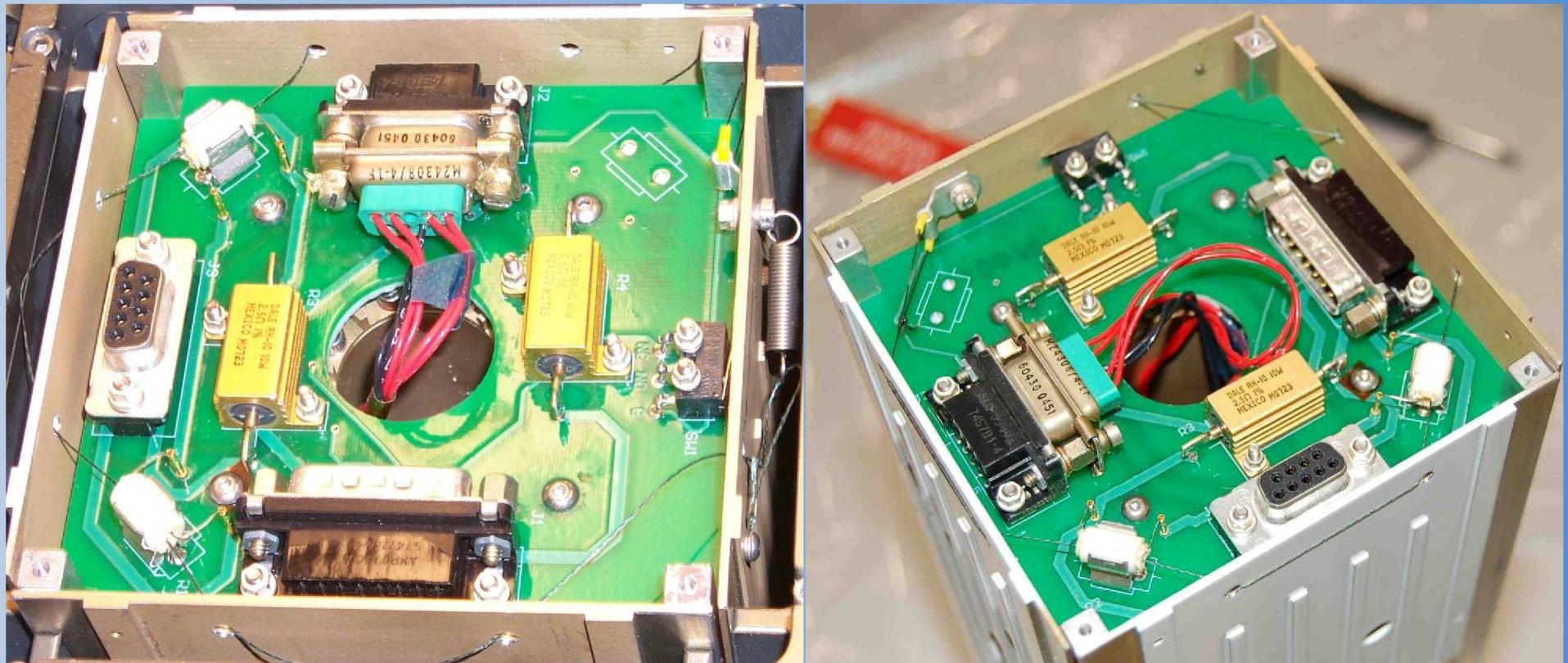
Little details are very important!



Verify your analyses with tests!

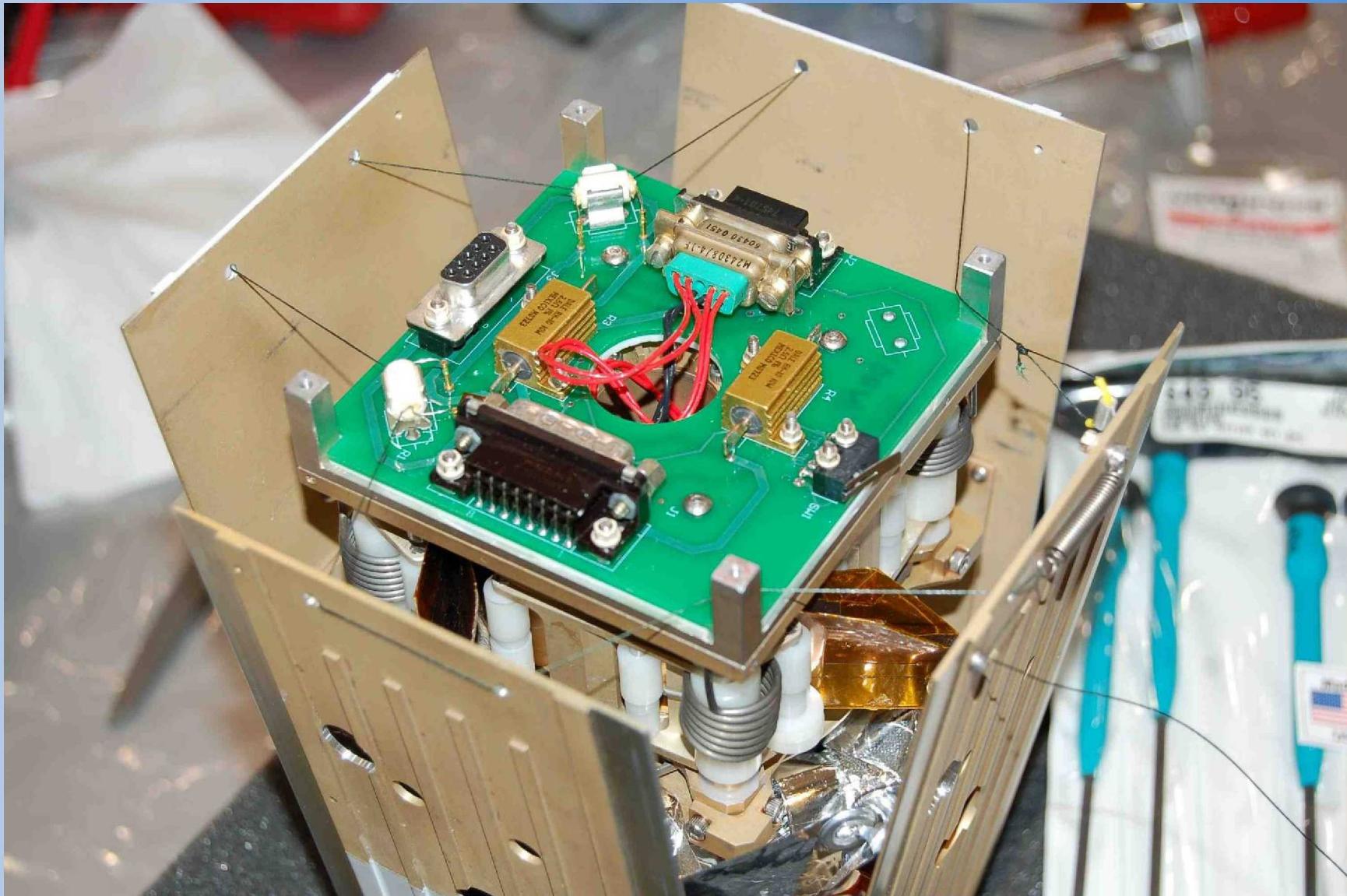
Problems will happen!

Can you spot the problem? What is the cause for failure?

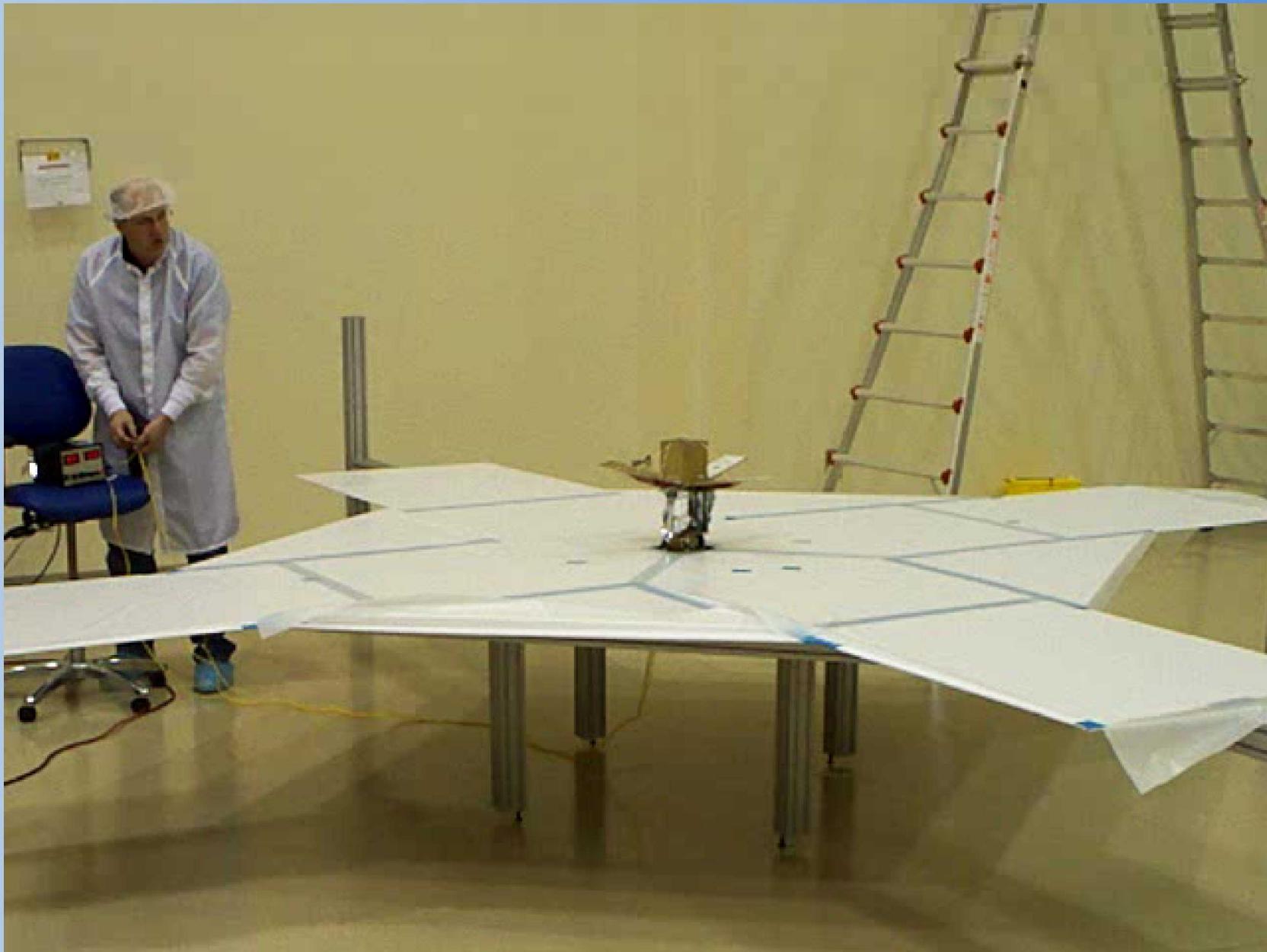


The difference between success and failure is the ability to identify the problem, the root cause and how to solve the problem.

Solution!



Enjoy the success of your hard work!



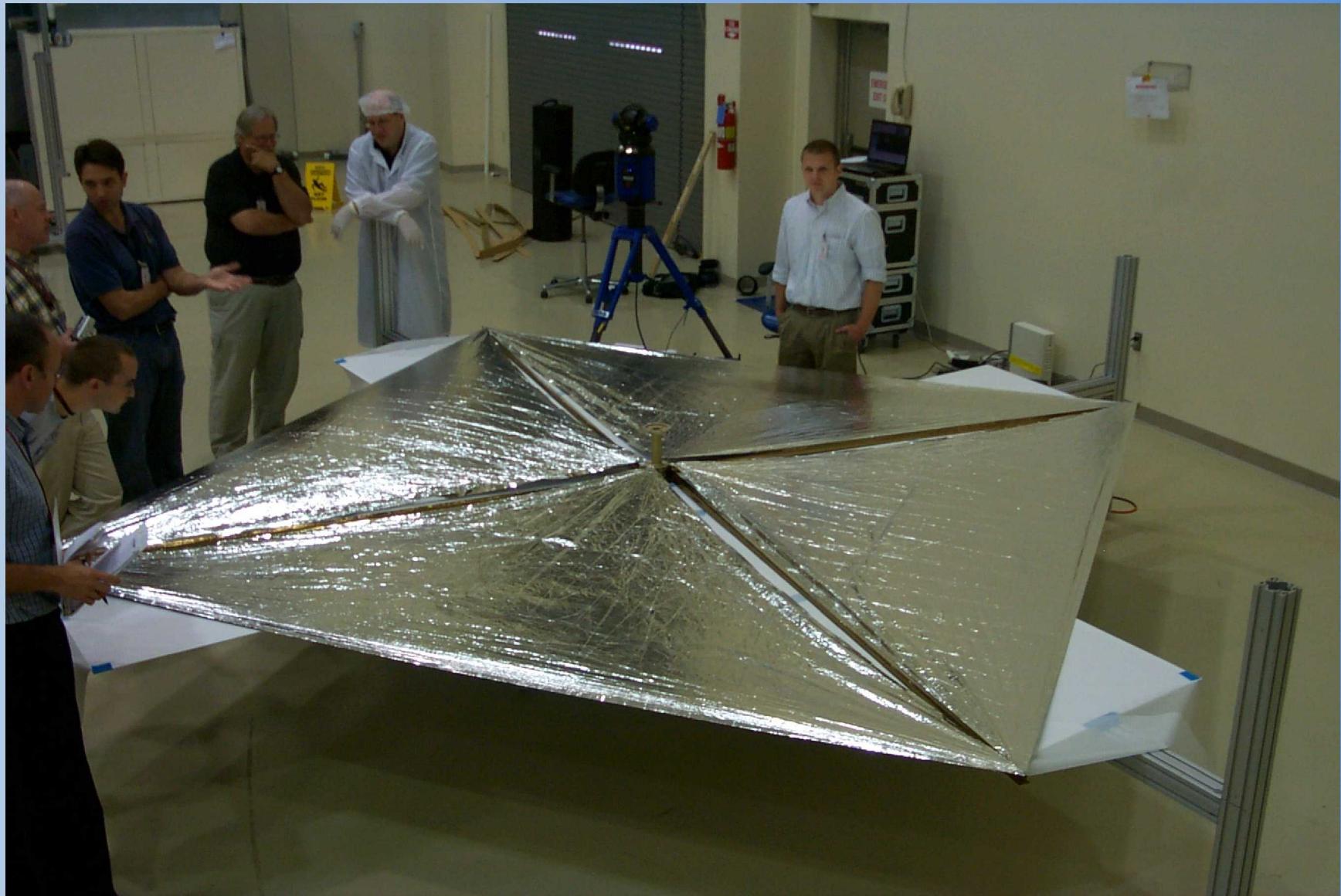
Having fun with your Job

1 day prior to launch	It's been a long wait, but only 1 day left. Check out the launch @ URL.
2 hours prior to launch	Is there a bathroom around here? I've been holding for weeks.
30 minutes prior to launch	I'm just a little nervous about what is actually out there. Is there any way #2 can take my place? Please?!!
5 minutes prior to launch	Well, #2 couldn't make it. I guess I'll just have to enjoy the ride.
Falcon-1 Launch	Aaaaaaaaaaaaaaghoooooooooooo!!!!!!
Initial Launch	Somebody slow this thing down! I want to get off!!!!!!
Mid Launch	Ok breathe now, In ... Out ... In ... Out., It's not helping! Aaaaaaaaaaaaaaghoooooooooooo!!!!!!
	I'm on the internet now @ URL. Can you see me? I'm waving.
@ 1st Stage separation	What was that bang? Did you see that? Part of the rocket is falling away!
@ 2nd Stage ignition	Must have been the first stage. Aaaaaaaaaaaaaaghoooooooooooo!!!!!! Here we go again!

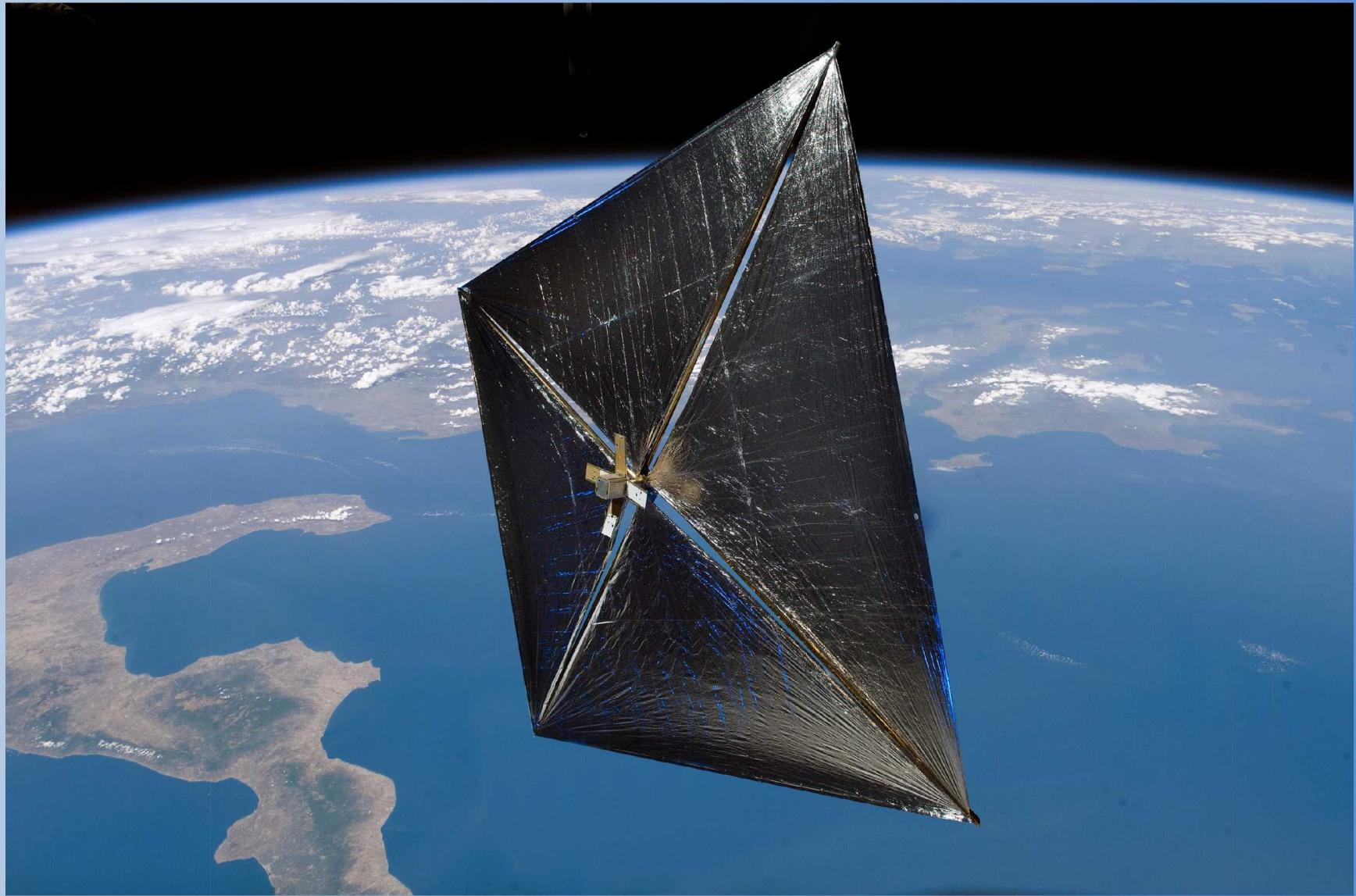
Making other people laugh and enjoying teamwork



Helping others helps you!



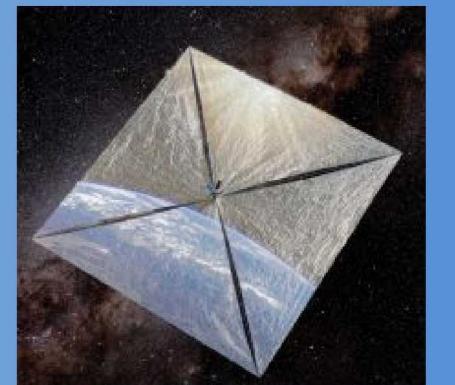
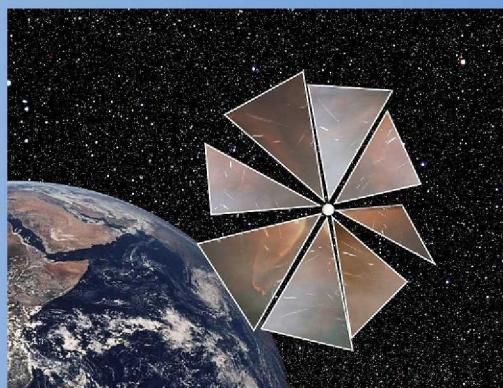
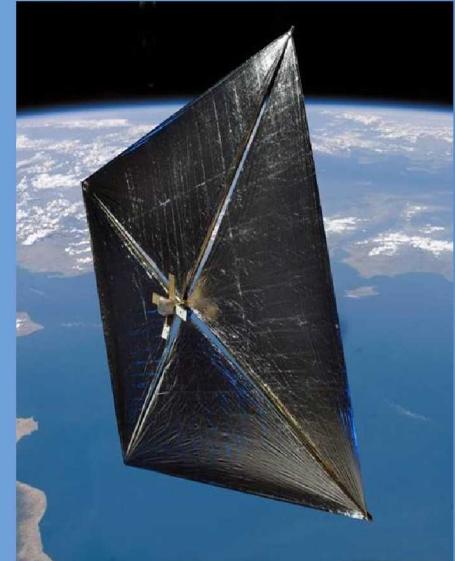
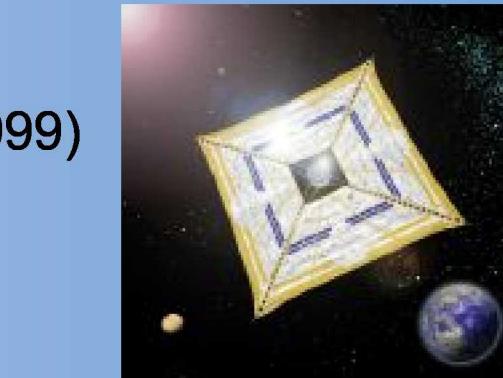
Pictures help others to “see” your ideas



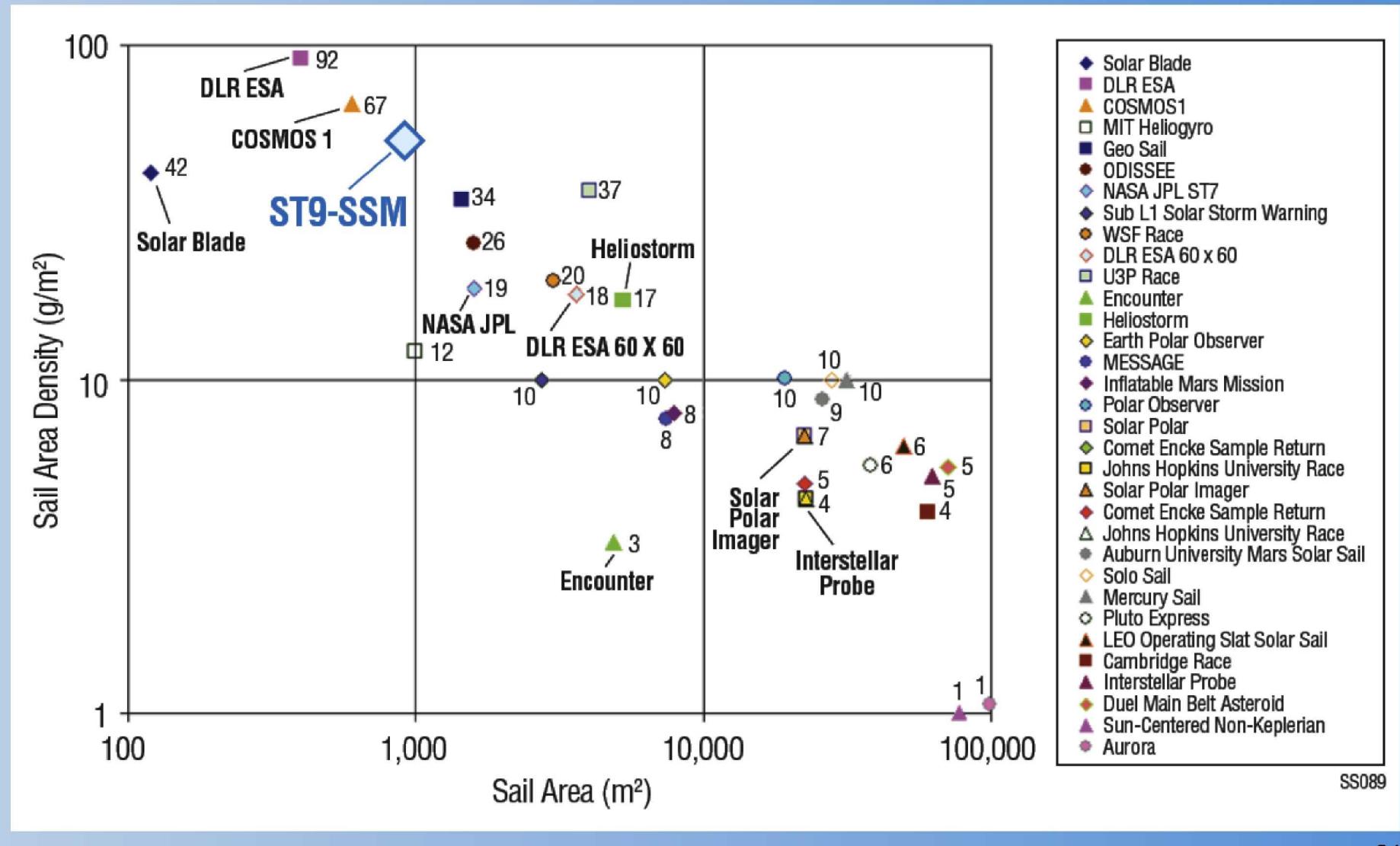
Brief History on Solar Sail Technology

Development and missions

- NASA
 - Mariner 10 – (1970's)
 - NASA – ST9-SSM (2006)
 - NASA's – NanoSail-D (2008), NanoSail-D2 (2010)
- Russian
 - Znamya 2 & 2.5 – (1993, 1999)
- JAXA
 - “Cloverleaf” – (2004)
 - Solar Sail Payload – (2006)
 - Ikaros – (2010)
- The Planetary Society
 - COSMOS 1 – (2005)
 - LightSail 1 – (2011?)



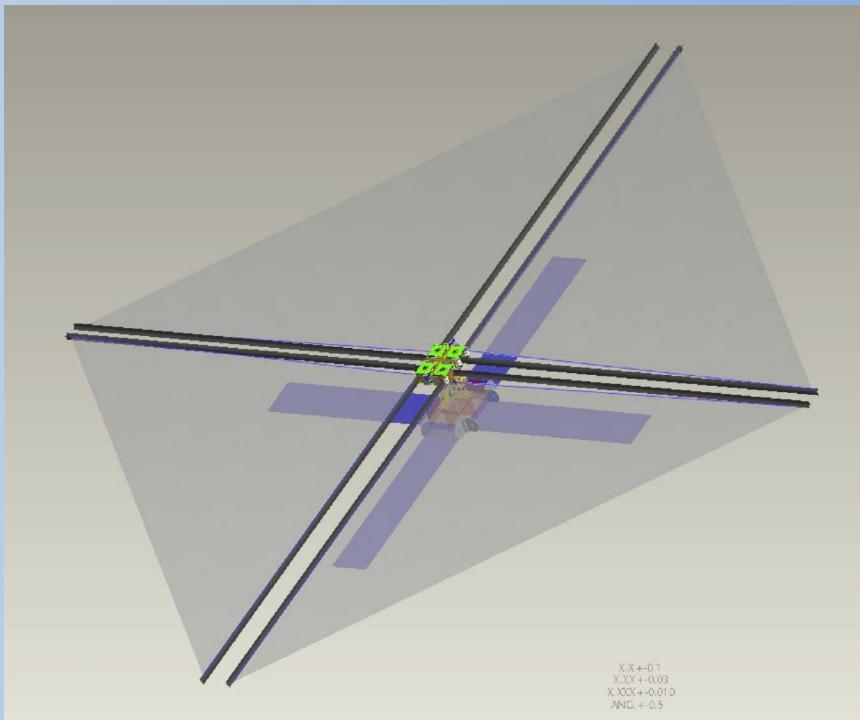
Areal Density for Solar Sail Missions



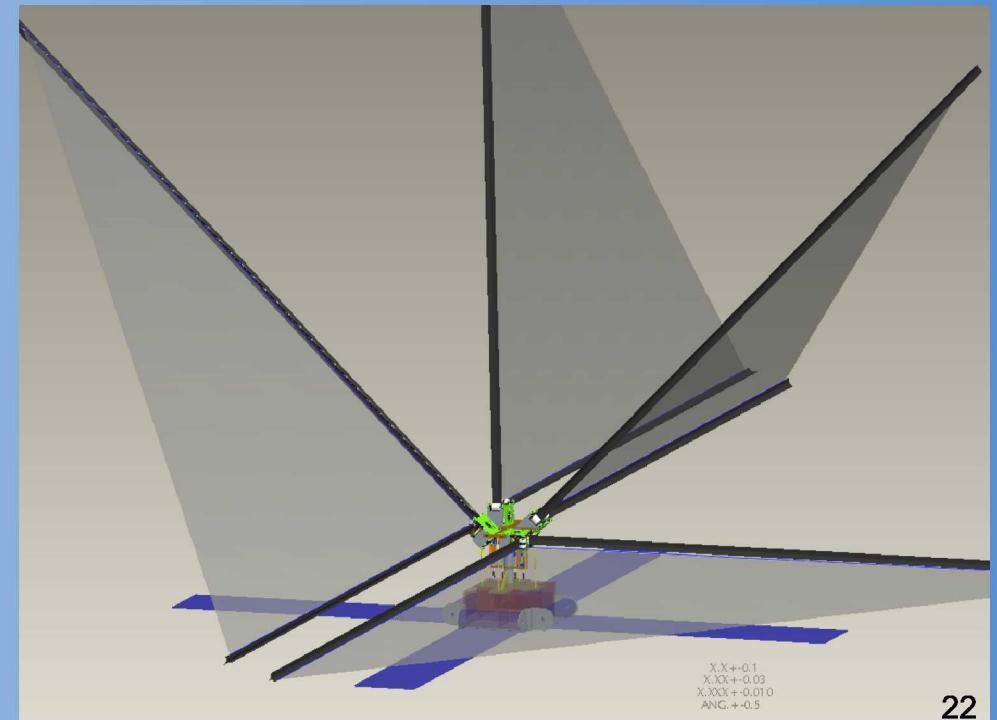
FeatherSail Goals

- Leverage NanoSail-D design heritage
- Design sail rotation/steering mechanism
- Investigate recent technology innovations

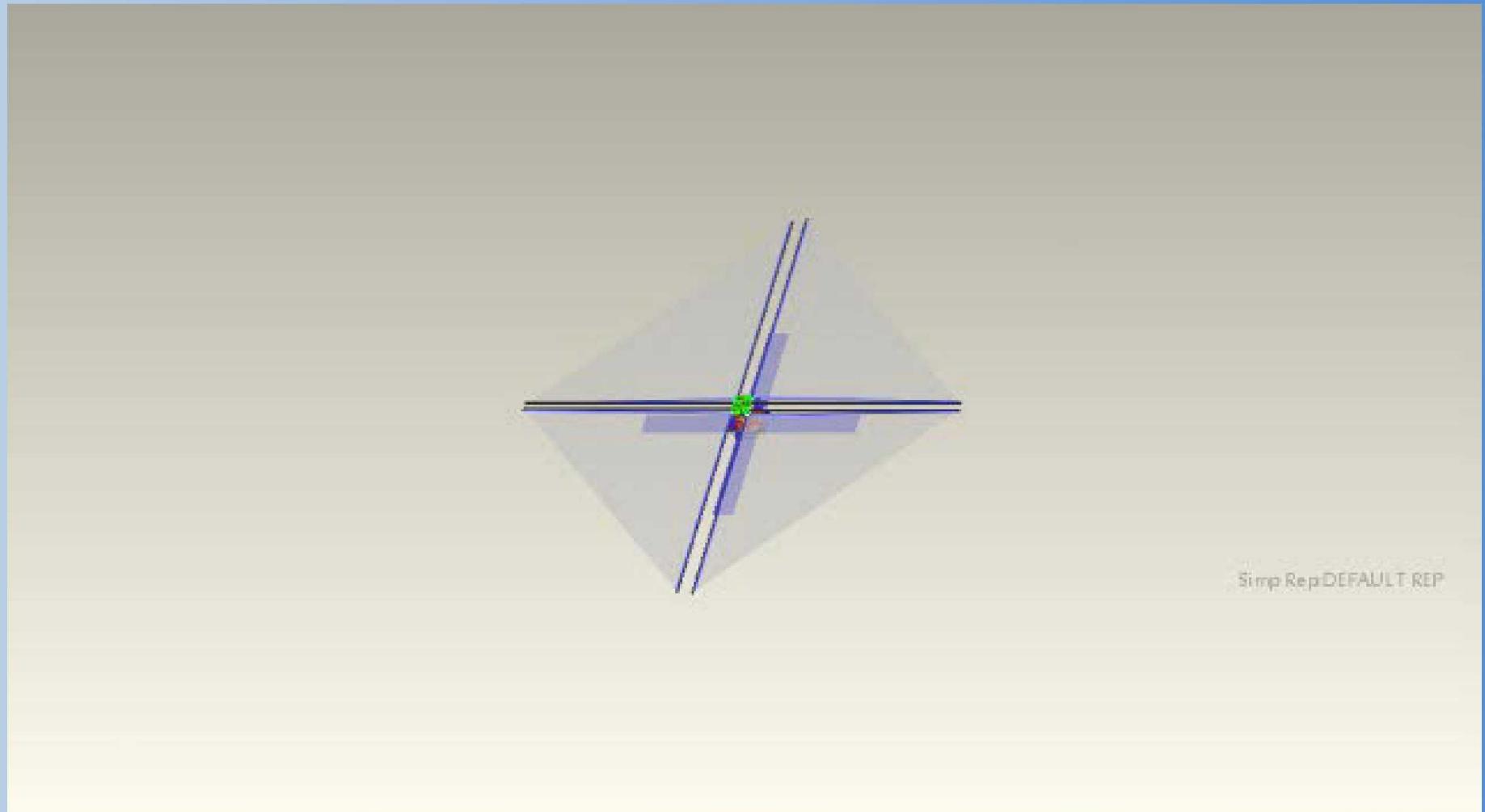
FeatherSail with deployed sails



FeatherSail with angled sails

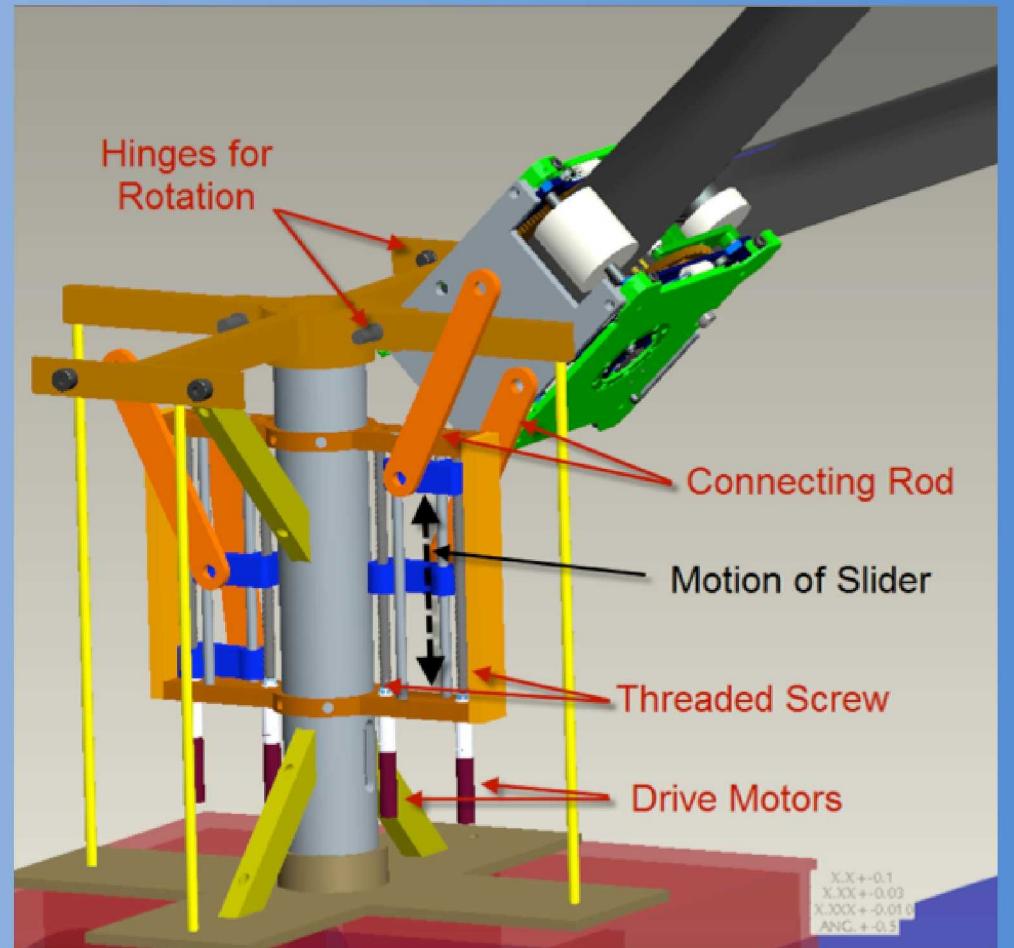


FeatherSail Animation



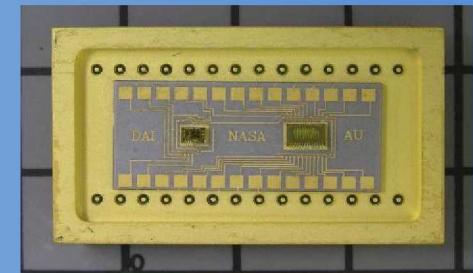
Sail Rotation Mechanism

- NanoSail-D boom deployer
 - Modify to deploy only 2 booms
 - Add hinge points for rotation
 - One design for all 4 locations
- Simple slider mechanism
 - Rotate booms/sail 90°
 - Minimize required volume
 - Slider mechanism
 - Brushless DC drive motors
 - Absolute thin film SCAPS position sensor on slider



Recent Technology Innovations

- Thin Film Solar Cells
 - Low mass per unit area
 - Lower cost vs. conventional cells
 - Requires deployment method
 - Use design similar to NanoSail-D booms
 - Could possibly be integrated into solar sail membrane
- Silicon-Germanium (SiGe) electronics
 - Low power even at high speed
 - Radiation tolerant
 - TID + SEE tolerant, SEL immune
 - Extreme temperature range (-180°C to +120°C)



How do you know when an idea is good or great?

- What is a PDA?
 - Personal Digital Assistant
 - Coined by Apple for Newton (late 1992)
 - Newton arrived on market in late 1993
 - Palm made the first widely accepted PDA (1996)
 - Transitioned to smartphones
 - Blackberry, Droid, iPhone, iPod touch, iPad, etc.
 - Current 2010 market is 150M units/year (PDA 3M/yr)



How many of you own one or more PDA's or smartphones?

YOU OWE ME ROYALITIES!

Design of NoteTaker

came to me
watching Star Trek)
The character "Wesley" was doing
some figuring on a slate which
had all the capabilities of a computer
(finger entry)

Idea: Build a device to take input
from a writing device and store
in a plot file. Design for MAC
and PC's.

Market: College students and any one
who has to take notes.

Reason: Eliminate paper waste. Don't
need notes, erase from disk
memory etc.

Existing products: Gridpad and Datallite

The problem with these products is that
they are too advanced for the regular user
and too costly.

Price Range \$100-\$300

Features

Cheap. (Inexpensive)
Simple
Provide a simple means of
taking notes by hand and storing
electronically

Place some type of software that
recognizes (ASCII) characters and
fits them in a format - not real time
though - later at convenience - of
user.

The program should be designed
using Neural Nets so that it becomes
customized to the user in character
recognition

Main Components

Power Supply (Plastics - LiV Rechargeable)
Input - Touch Sensitive Screen
Feedback - Back lit - display

Microprocessor

Software

Connections - Hardware - Software (P/T)

So what is the next great idea?

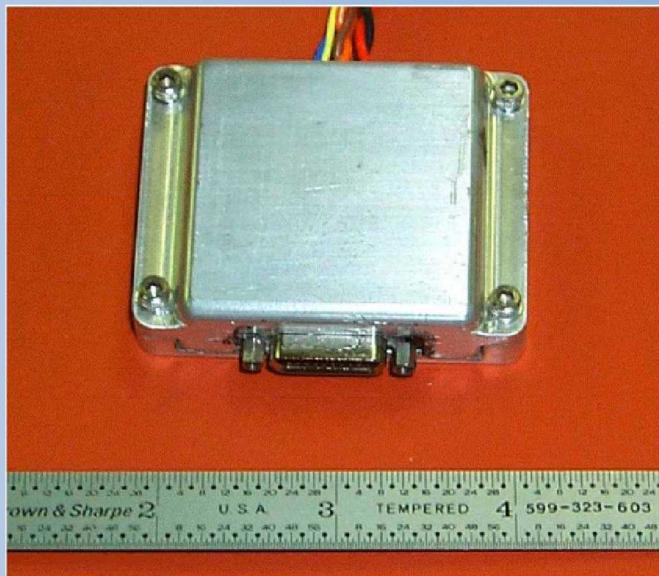
SMART

Small Multi-purpose Advanced Reconfigurable Technology

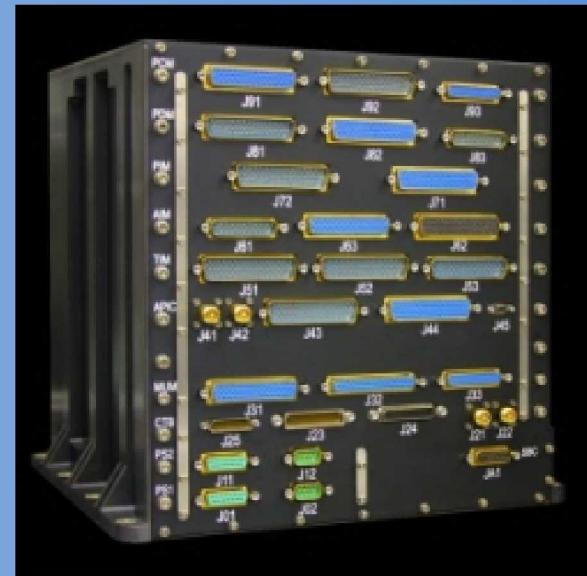
- SMART technology is based upon two small, distributed, standard hardware devices, that can provide control and sensing functions for multiple end-item avionics applications
 - SMART Drive Module (SMART-D)
 - Motors, Valves, Solenoids, Power Distribution, Heaters, Pin Pullers, Thermostats, etc.
 - Limited sensor inputs for local closed loop control
 - SMART Sensor Module (SMART-S)
 - Thermocouples, RTD's, Potentiometers, Encoders, Tachometers, Resolvers, Accelerometers, Gyros, Pressure Sensors, etc.
 - Module can provide limit checking of sensor outputs
 - SMART units can be reprogrammed for different applications
 - SMART unit software will only have to be developed for a function if it has not already been developed for a previous application
 - SMART units would arrive flight qualified and can “interface” with avionics much earlier in the spacecraft development cycle

Why SMART?

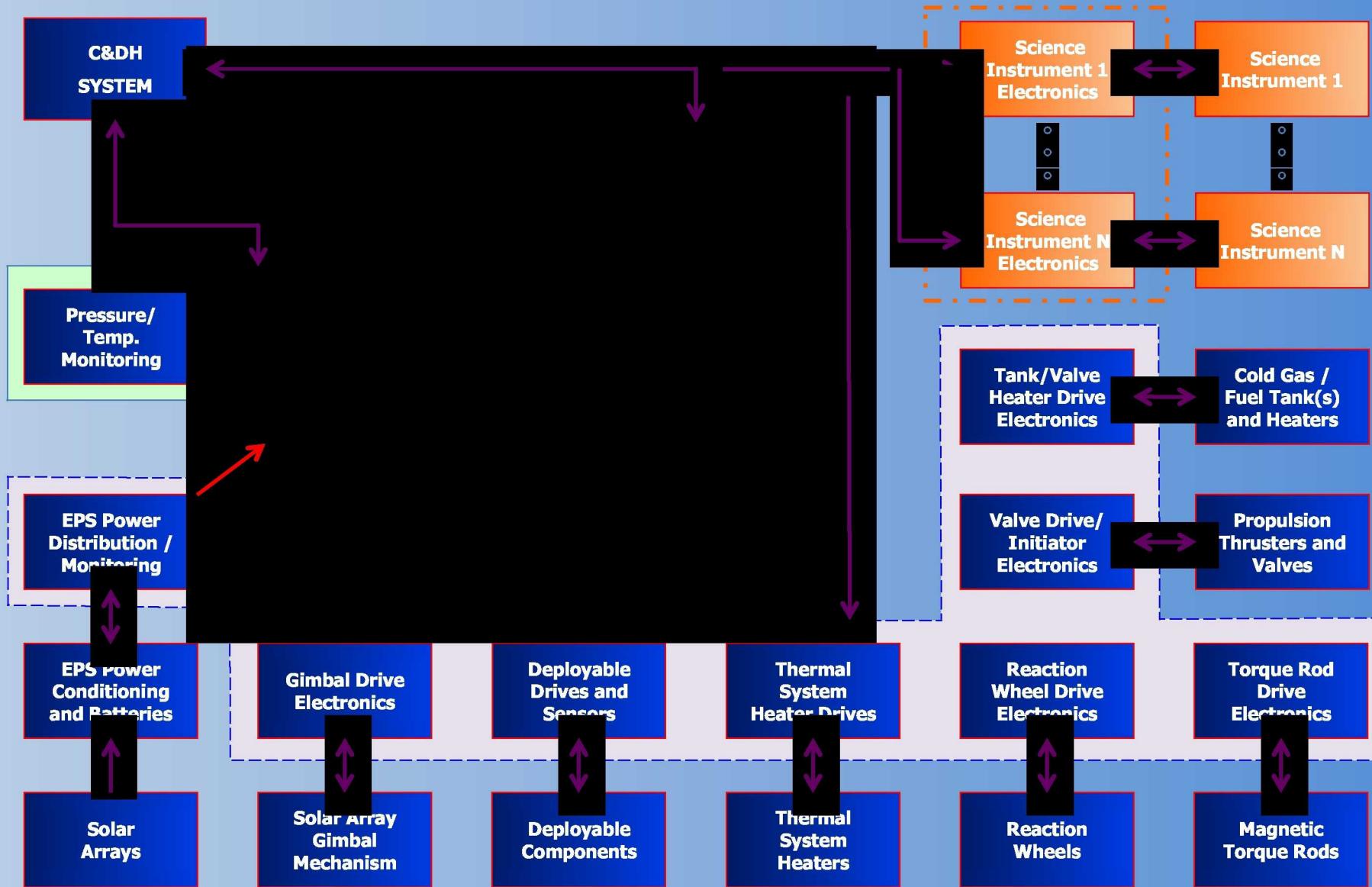
Property	SMART	Power Distribution Unit
Size	~ 100cc	Varies ~ 3500cc
Power	~ 0.25W, .0005W (sleep)	~ 20+ Watts continuous
Mass	~ 0.15kg	~ 20 – 35kg
Cost	~\$2500 - \$25k (no NRE)	\$100k - \$M (+ NRE every time)
Schedule	Off the Shelf	2 – 5 years ATP



vs.



SMART Applications in Typical Satellite Avionics System



How do you know when an idea is great?



SMART Concept Benefits

- Significantly reduces (or eliminates) the development cycle time by standardizing drive and sensor functions
 - Standardizing reduces testing and integration costs (Qualify by similarity)
 - Increased production scale lowers piece part cost
 - Concept influences designers to specify components that interface directly and easily with SMART modules
 - Allow system design to proceed earlier in development cycle
- Simple interfaces between systems
 - Only communication and power lines are run from SMART modules to main avionics systems
 - Standard connections on both sides of SMART modules
 - High current is switched at the application point (reduces EMI)
- Modules can be reused after initial purpose has been achieved
 - Altair valve driver could be scavenged and reprogrammed on moon for alternative use (Heater controller, motor controller for water recovery, etc.)

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SMART Concept Benefits (continued)

- Greatly reduces or eliminates nonrecurring engineering (NRE) costs for control and sensing electronics
- SMART NRE would involve just programmable SW (if anything)
 - SMART SW development and validation can occur early in program
 - Component suppliers have a vested interest to provide driver programs for standard modules and may have SW on shelf already
- Driver SW programs can be reused for similar applications
- Flexible to late requirement changes
 - Ability to add functions late into system design, even during integration
 - Modules can be reprogrammed or replaced as needed
 - Reduces cost and schedule impacts
- SMART units are small, so device layout onto the S/C is simple and flexible
- End products have wide ranging space and commercial applications

6



Advantages of Distributed vs. Centralized Architectures

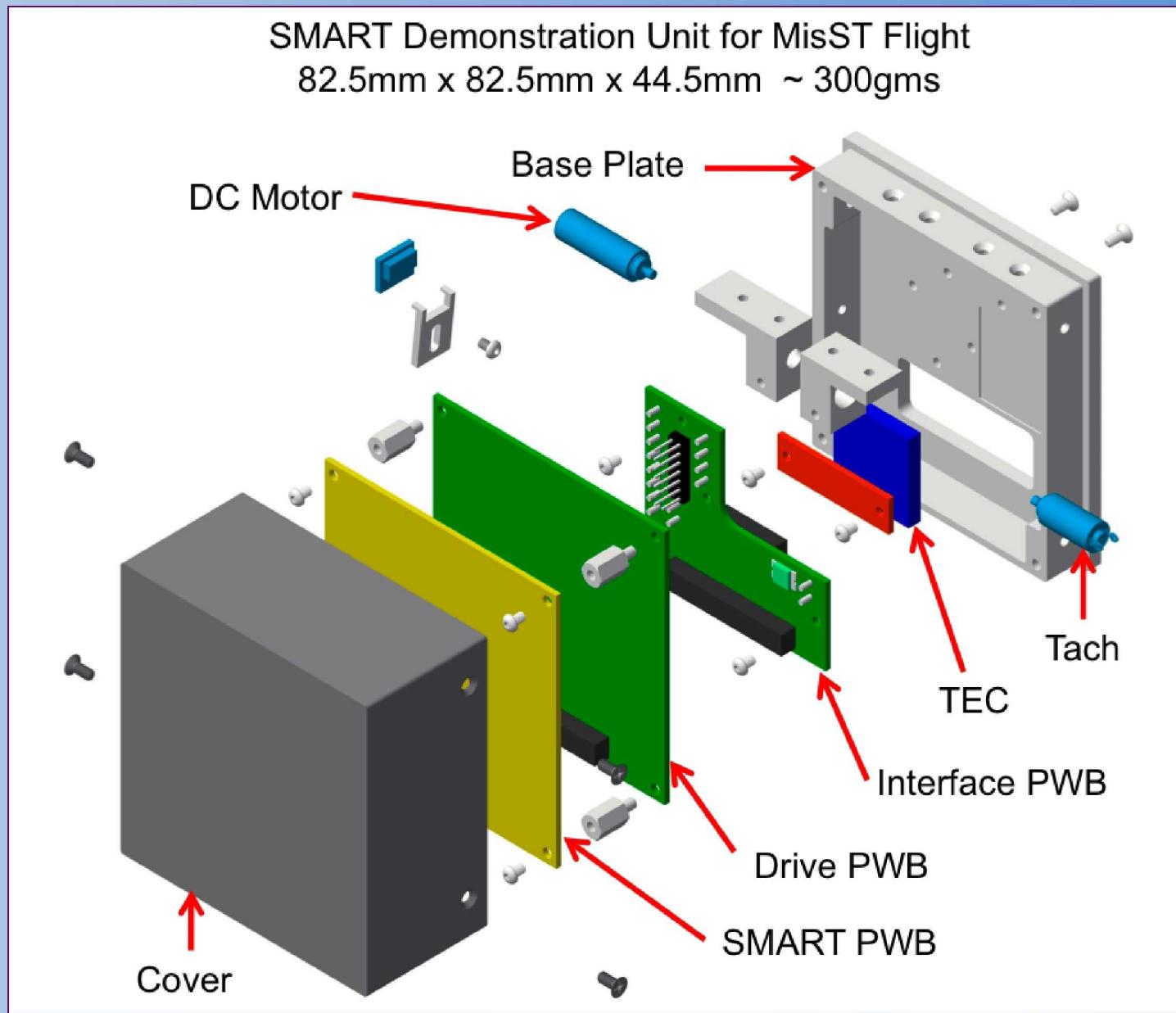
- Advantages and disadvantages are application dependent
 - Highly integrated systems should be centralized (ie, Mars Rover)
 - Systems with remote functions are better candidates for distributed sensing and control (Satellites, landers, vehicles, etc.)
- Co-location of sensors and electronics (ideal control situation)
 - Less signal loss from sensitive sensors
 - Control of actuators is performed locally
 - Minimizes time lags and increases drive control bandwidth
 - Limit checking at lower level reduces overhead on main processor
- Centralized systems require high-speed processors and communication systems which are complex, costly and have significant issues with radiation hardening
- Distributed systems lower mission cost due to:
 - Reduced wiring mass
 - Individual modules are considered line replacement units (LRUs)
 - Faults are more easily discovered and repaired

8

1. When there are many more benefits than disadvantages
2. When the cost is much less than the competition
3. When the idea will change the state-of-the-art
4. When the idea has many different applications

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SMART flight Demonstration Unit



So now what? You have the idea, what do you do with it?

- Ideas are just that, ideas. (Dime a dozen)
- You must work out the concept to make sure that someone will want to buy/invest in your idea.
- Market the idea in the correct area, i.e. don't sell rocks to a window manufacturer.
- Apply the idea in a small way to grow the concept.
- Don't give up!
 - Edison had thousands of failures before the light was invented. Each time he found out how to NOT make the light bulb!



In conclusion

- Solar sailing is in its infancy
 - Great strides in solar sailing will occur over the next decade
- NanoSail-D to be launched no earlier than October 1st, 2010
 - Will be on orbit 70-120 days
 - Provide valuable information about stowing and deploying sails
- FeatherSail concept to be developed over next few years
 - New technology advances will enable future capabilities
- Future ideas and research is necessary for the continued development of space systems
 - SMART has the potential to revolutionize spacecraft avionics